The Jet Latitude Dependence on the Surface Friction

Advisor: Isaac Held

Gang Chen
Program in Atmospheric and Oceanic Sciences

Overview

- Introduction

  The jet latitude is sensitive to the surface friction change.
- Numerical experiments

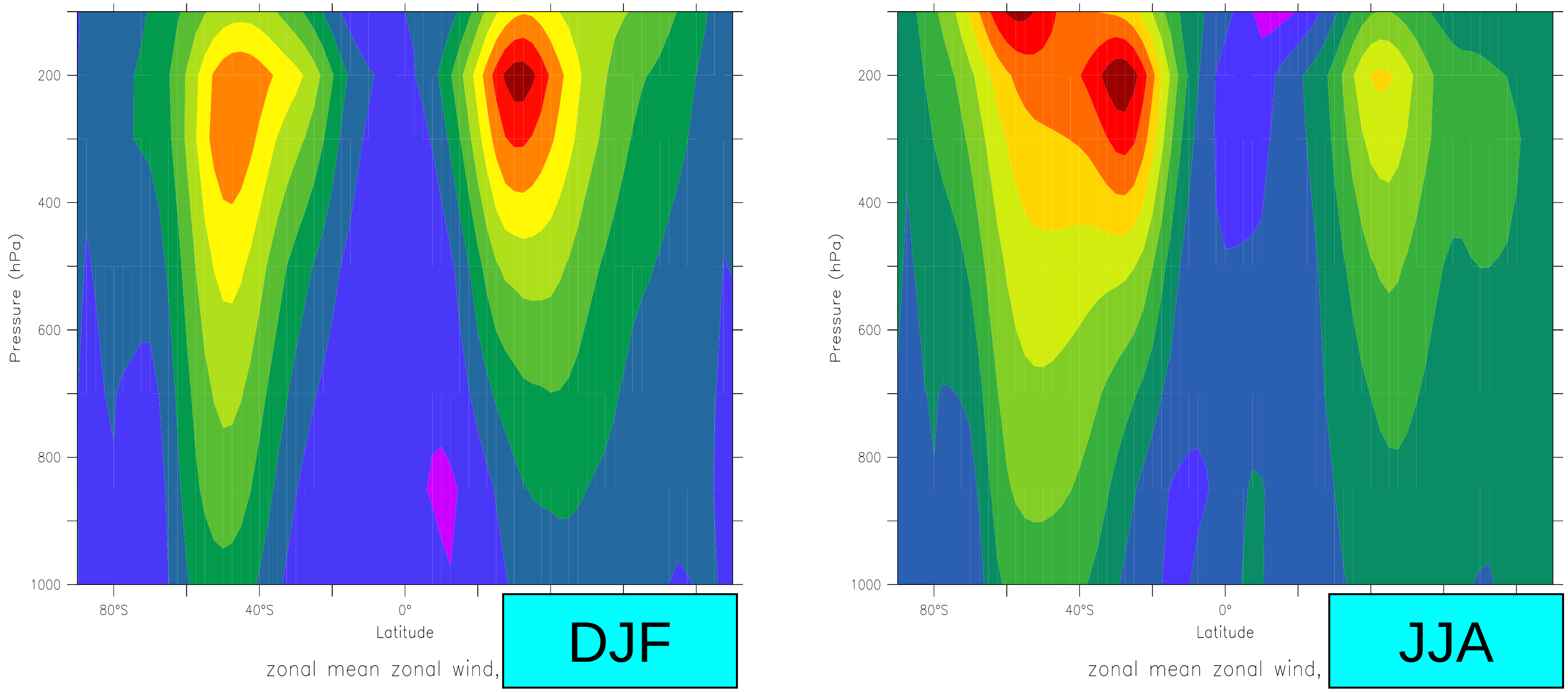
  1. Model description and characteristics
  2. Sensitivity to various values of surface friction
  3. Sensitivity to various values of friction acting on eddy or mean flow
  4. Ensemble experiments
  5. Diagnostics in the PV perspective of views
- Summary

Introduction

Factors that could affect the position of jet stream

➢ Solar Radiation:

Climatologic mean of zonal wind, ECMWF(1980-90)



Jet latitude: 30º-35º during winter, 40º-45º during summer

Introduction

- Greenhouse gases/Global warming

  Doubling CO_2 has significant impact on the tropospheric circulation (Kushner, Held, Delworth, 2000)

- Stratosphere-troposphere coupling:

  Thermal perturbation in the stratosphere can induce a significant change of circulation in the troposphere (Polvani, Kushner, 2002)

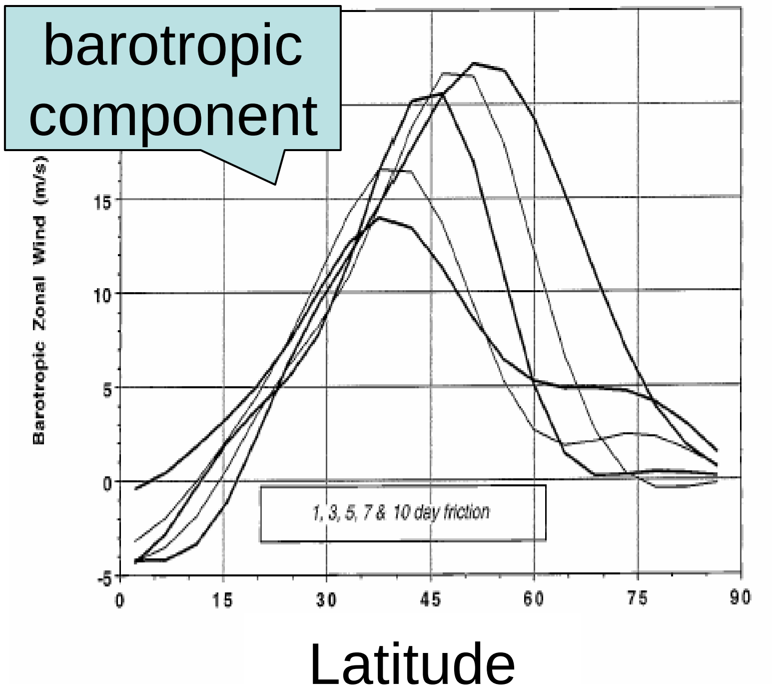
Simple atmosphere model

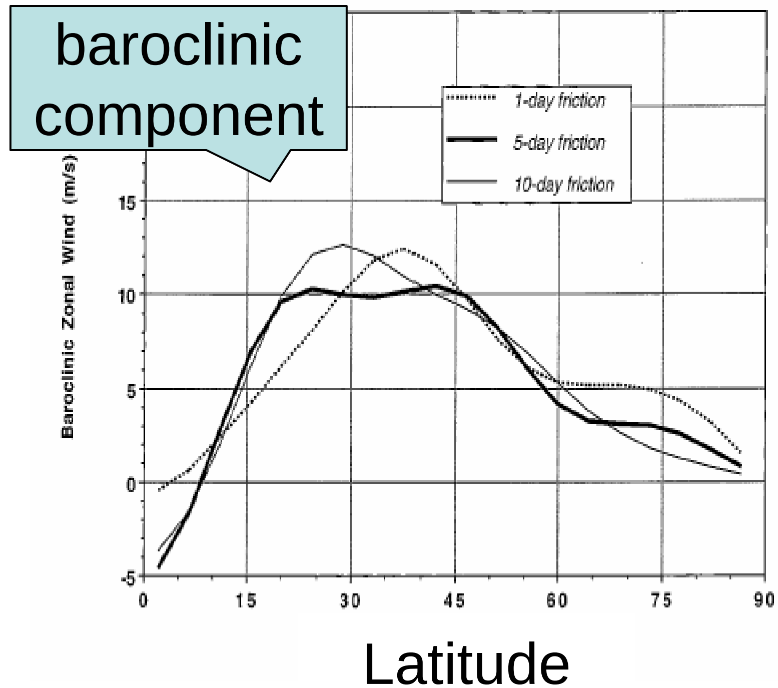
- Zonally symmetric radiative forcing
- Zonally symmetric dissipation
- No stratosphere
- No topography
- No ocean
- No water / dry atmosphere

- In an Earth-like climate, what determines the jet latitude?
  1. radiative forcing
  2. surface friction
  3. rotation rate

The role of surface friction

A global two-level primitive equation model (R15)





The jet moves poleward with decreasing surface friction.
(Robinson, 1996)

Numerical Experiments

- 1. Model description and characteristics
- 2. Sensitivity to various values for surface friction
- 3. Sensitivity to various values for friction acting on eddy or mean flow

  $\Rightarrow$ drag on the mean flow is more important
- 4. Ensemble experiments

  $\Rightarrow$ the instantaneous response of the atmosphere to the friction change on the mean flow
- 5.Diagnostics in the PV perspective of view

  $\Rightarrow$ two layer isentropic model

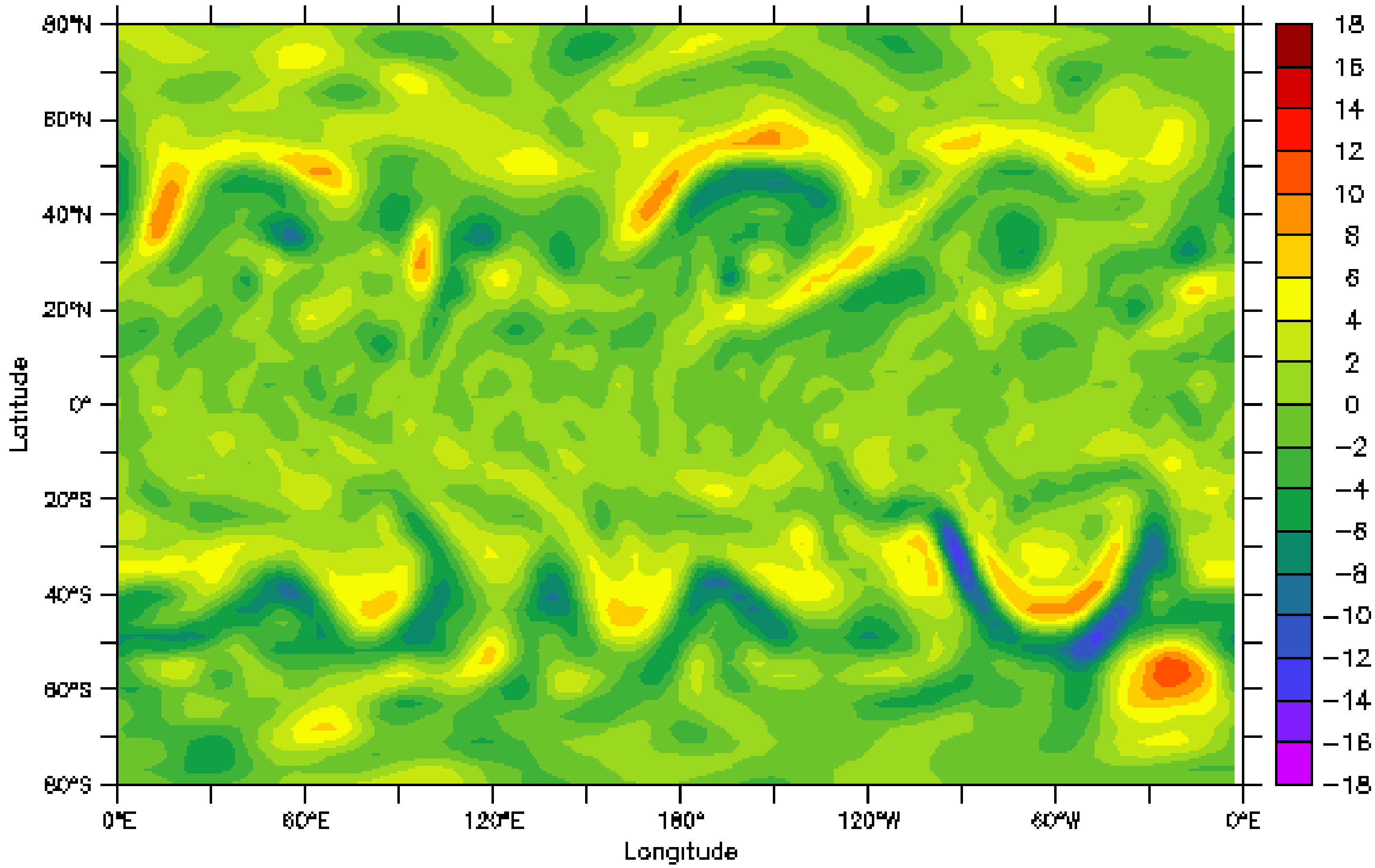
The idealized dry model

- GFDL atmospheric spectral dynamical core
- Held-Suarez Physics (Held, Suarez 1994)

$$
\begin{aligned}
\frac{\partial T}{\partial t} &= \ldots - k_T(\phi,\sigma)[T - T_{eq}(\phi,p)] \\
\frac{\partial \mathbf{v}}{\partial t} &= \ldots - k_v(\sigma)\mathbf{v} \\
k_v &= \begin{cases} 0 & \text{if } \sigma < \sigma_b \\ \frac{1}{\tau_f}\frac{\sigma-\sigma_b}{1-\sigma_b} & \text{if } \sigma > \sigma_b \end{cases} \\
\sigma_b &= 0.7,\ \boxed{\tau_f = 1 \text{ day}}
\end{aligned}
$$

- Zonally symmetric radiative forcing and surface friction
- Hemispheric symmetry
- No topography, no stationary waves
- T42, 20 vertical levels (much better resolution than Robinson!)
- The climatologic mean is independent of initial condition or the path to the statistically steady states

The statistically steady state



Vorticity at 275mb (day^{-1}) (latitude vs. longitude)

Numerical Experiments

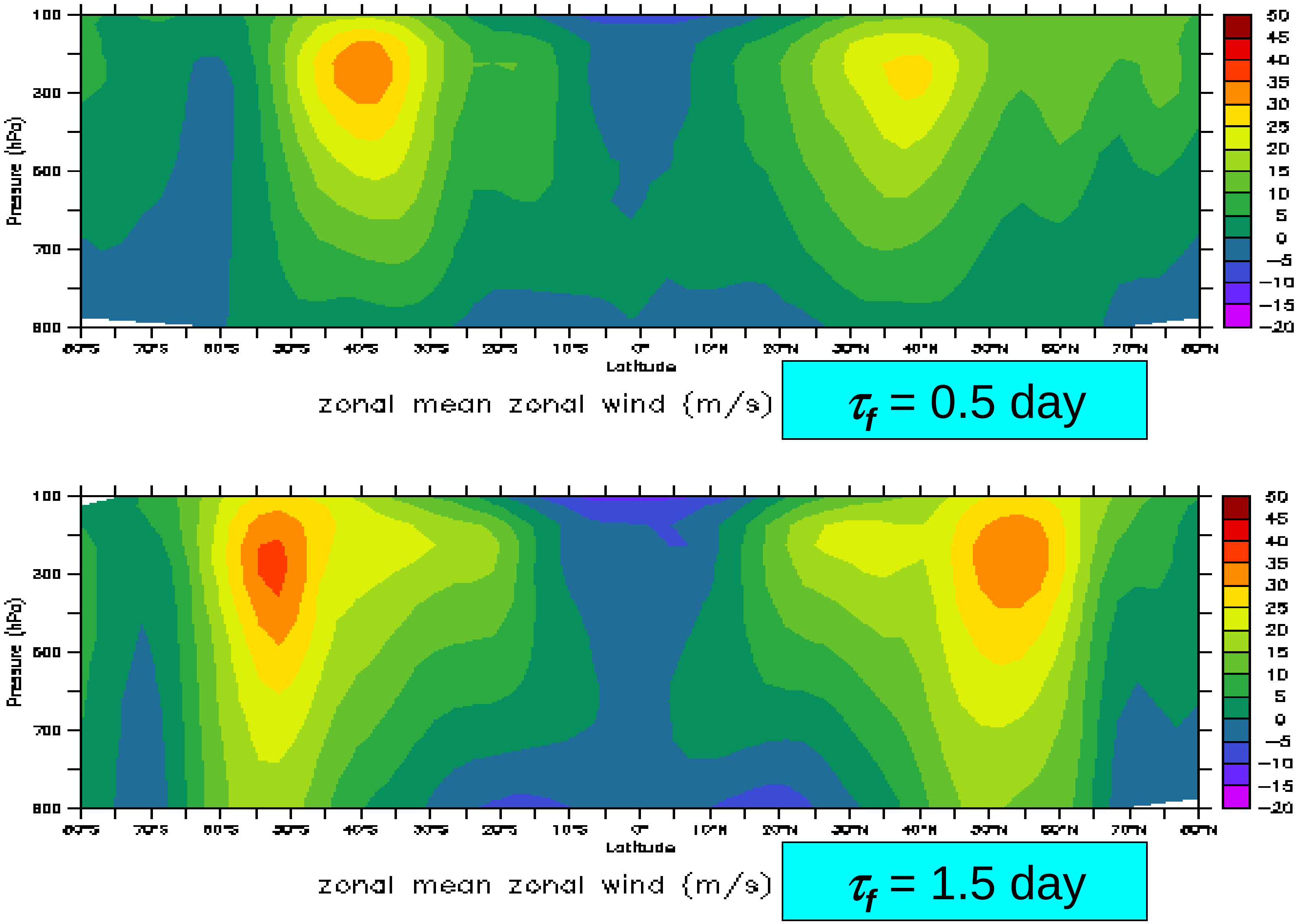
- 1. Model description and characteristics
- 2. Sensitivity to various values for surface friction
- 3. Sensitivity to various values for friction acting on eddy or mean flow

  $\Rightarrow$ drag on the mean flow is more important
- 4. Ensemble experiments

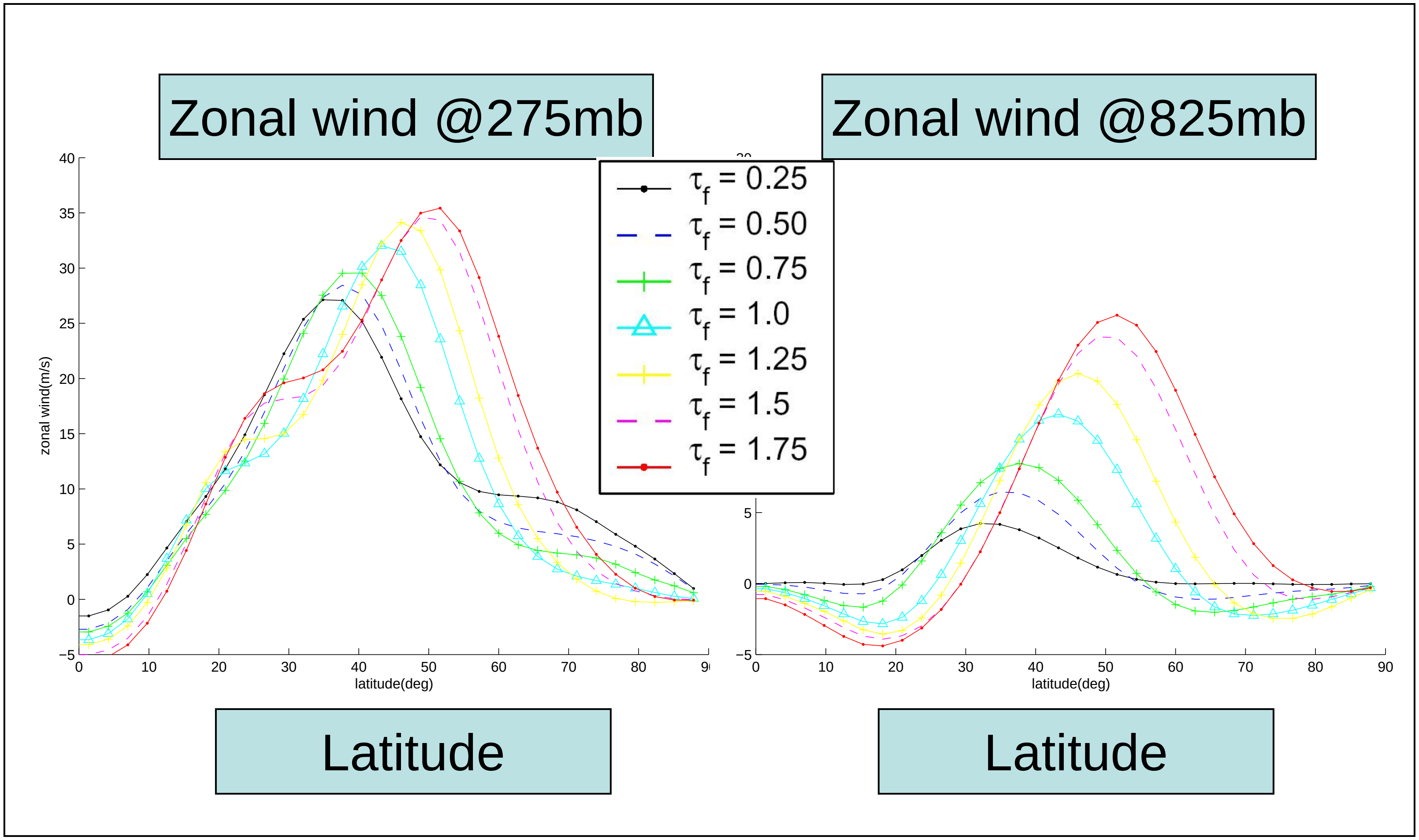
  $\Rightarrow$ the instantaneous response of the atmosphere to the friction change on the mean flow
- 5.Diagnostics in the PV perspective of view

  $\Rightarrow$ two layer isentropic model

Zonal mean zonal wind

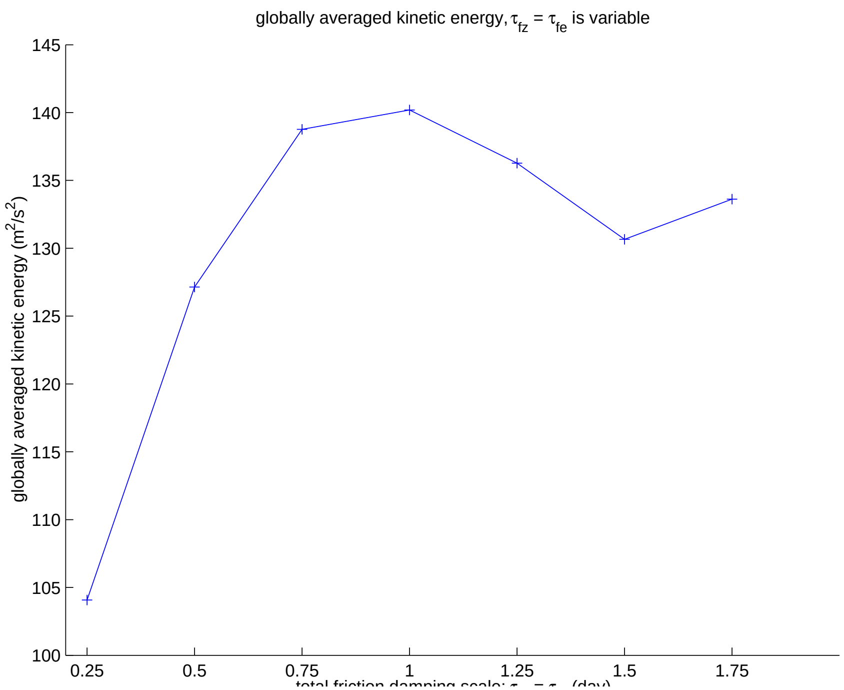


Time and zonally averaged zonal wind



The jet shifts polewards if the surface friction is reduced.
(Factor of 7 $\Rightarrow$ 15°-20° shift)

Time and globally averaged EKE



damping scale τ_f

But EKE is not monotonic !

Numerical Experiments

- 1. Model description and characteristics
- 2. Sensitivity to various values for surface friction
- 3. Sensitivity to various values for friction acting on eddy or mean flow

  $\Rightarrow$ drag on the mean flow is more important
- 4. Ensemble experiments

  $\Rightarrow$ the instantaneous response of the atmosphere to the friction change on the mean flow
- 5.Diagnostics in the PV perspective of view

  $\Rightarrow$ two layer isentropic model

The surface friction on the eddy or mean flow

The momentum equation with linear friction:

$$\text{mean:} \quad \frac{\partial \bar{u}}{\partial t} = \ldots - \frac{\bar{u}}{\tau_{fz}}$$

$$\text{eddy:} \quad \frac{\partial u'}{\partial t} = \ldots - \frac{u'}{\tau_{fe}}$$

$$\Rightarrow \quad \frac{\partial u}{\partial t} = \ldots - \frac{\bar{u}}{\tau_{fz}} - \frac{u'}{\tau_{fe}}$$

For any variable $\mathcal{X}(\tau_{fz}, \tau_{fe})$ in the model

1) $$\mathcal{X}(\tau_{fz}, \tau_{fe}) = \mathcal{X}(\tau_{f0}, \tau_{f0}) + \frac{\partial \mathcal{X}}{\partial \tau_{fz}} \delta\tau_{fz} + \frac{\partial \mathcal{X}}{\partial \tau_{fe}} \delta\tau_{fe}$$

2) $$\mathcal{X}_z(\tau_{fz}, \tau_{f0}) = \mathcal{X}(\tau_{f0}, \tau_{f0}) + \frac{\partial \mathcal{X}}{\partial \tau_{fz}} \delta\tau_{fz}$$

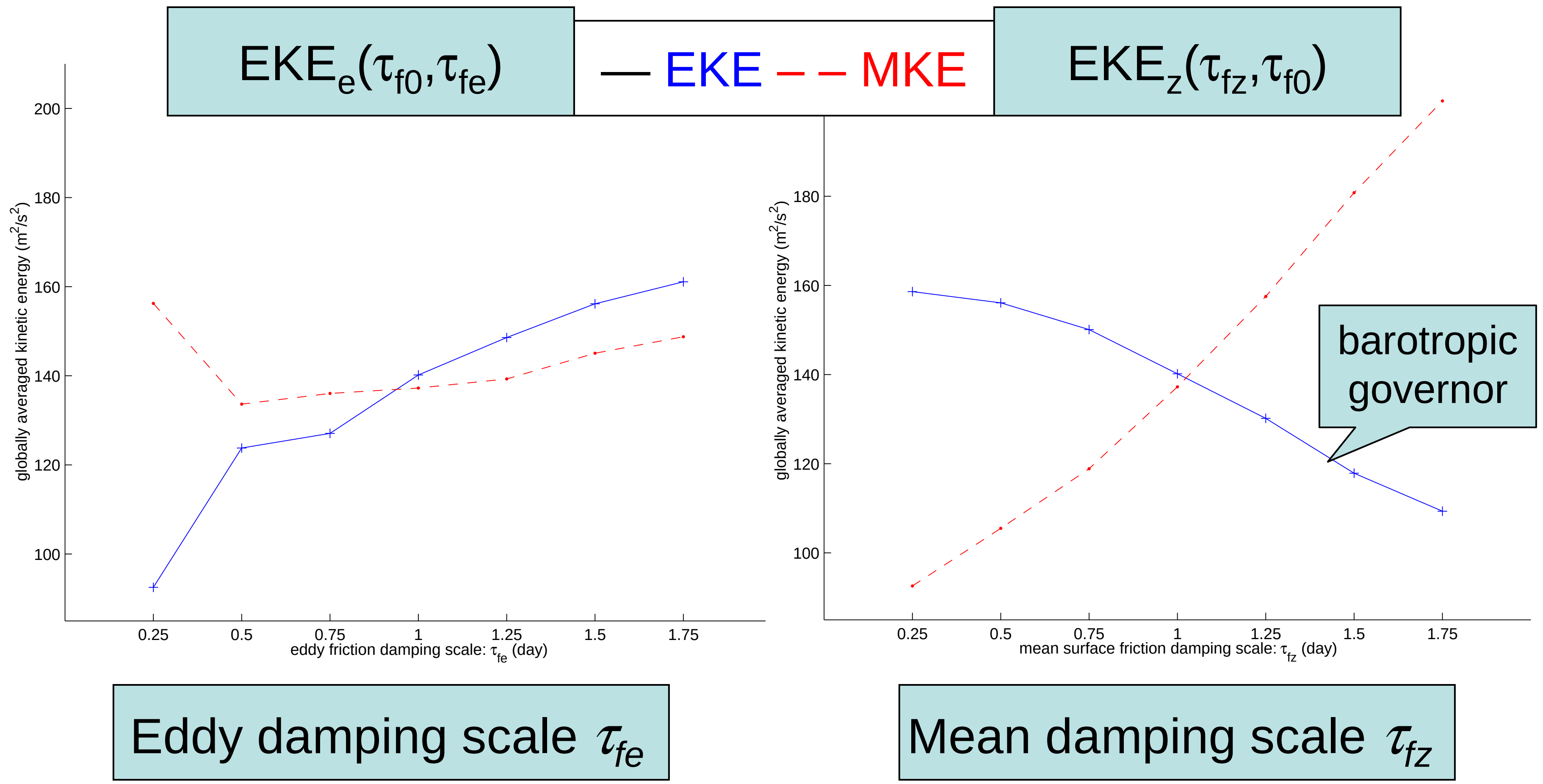
3) $$\mathcal{X}_e(\tau_{f0}, \tau_{fe}) = \mathcal{X}(\tau_{f0}, \tau_{f0}) + \frac{\partial \mathcal{X}}{\partial \tau_{fe}} \delta\tau_{fe}$$

4) $$\mathcal{X}'(\tau_{fz}, \tau_{fe}) = \mathcal{X}_z(\tau_{fz}, \tau_{f0}) + \mathcal{X}_e(\tau_{f0}, \tau_{fe}) - \mathcal{X}(\tau_{f0}, \tau_{f0})$$

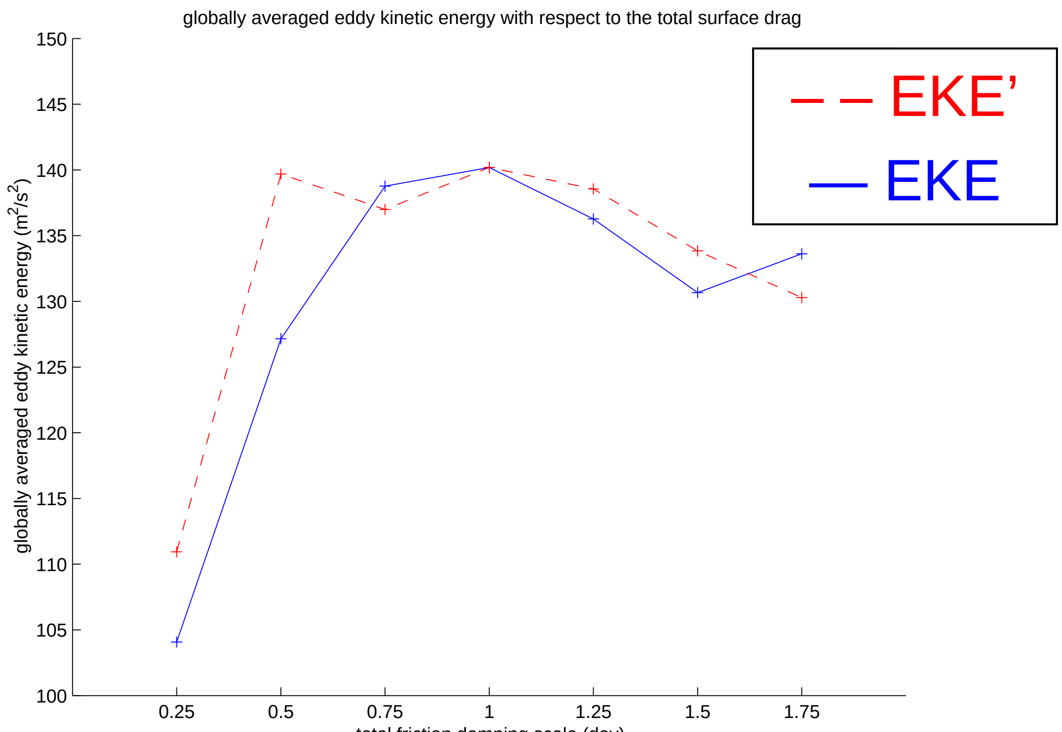
1)$\mathcal{X}$ = 4)$\mathcal{X}$'
if linear

$\Rightarrow \mathcal{X}$ = EKE, u

Globally averaged EKE



Globally averaged EKE



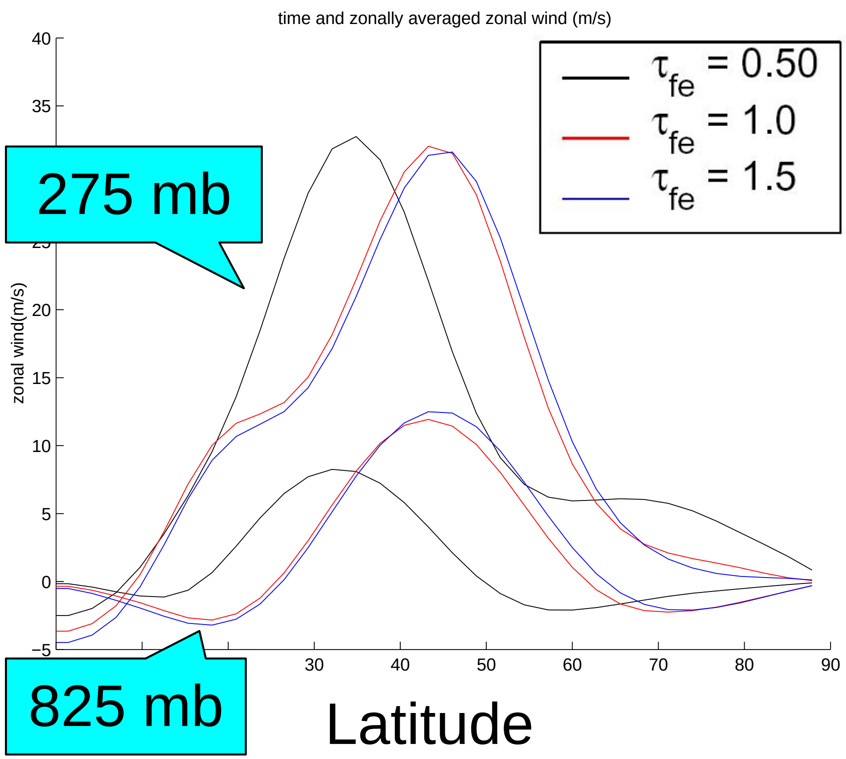
Damping scale τ_f

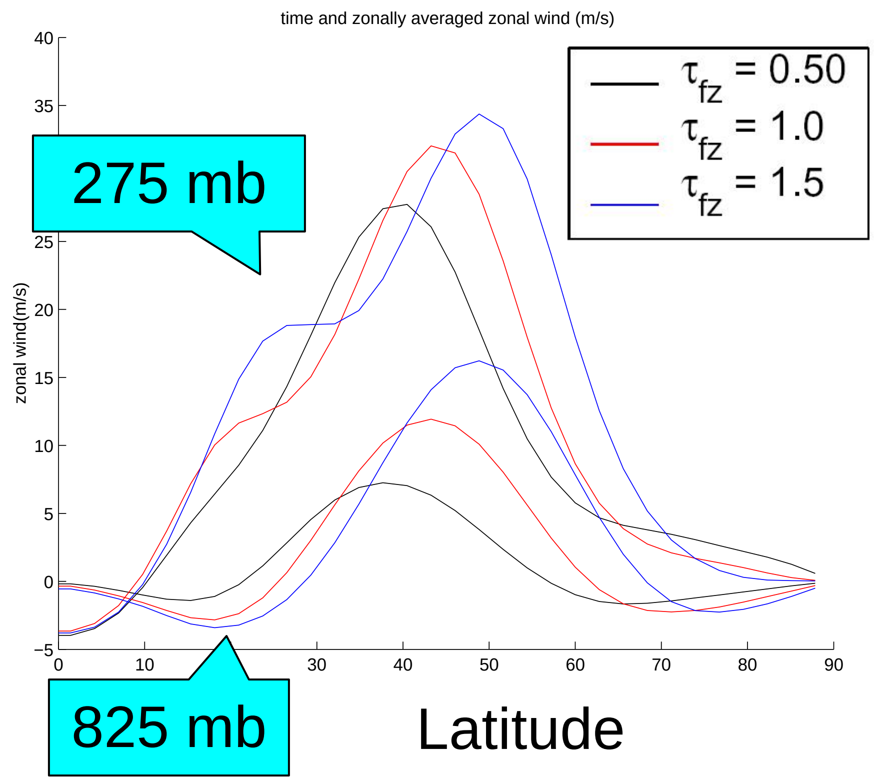
The variations of EKE with the mean damping and eddy damping are linear in the model parameterization range

Zonal Wind @275mb and 825mb

$u_e(\tau_{f0},\tau_{fe})$ (eddy damping)

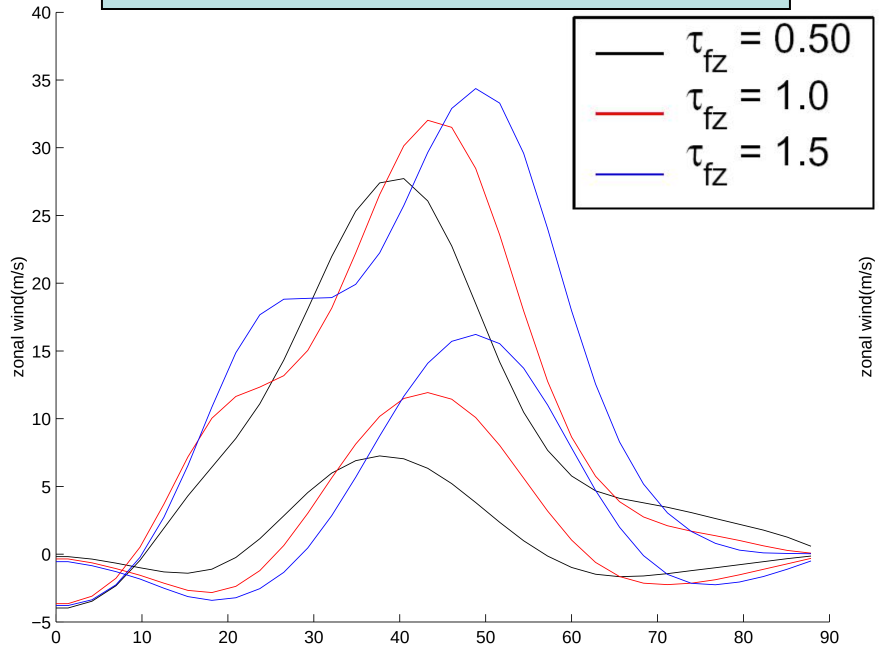
$u_z(\tau_{fz},\tau_{f0})$ (mean damping)





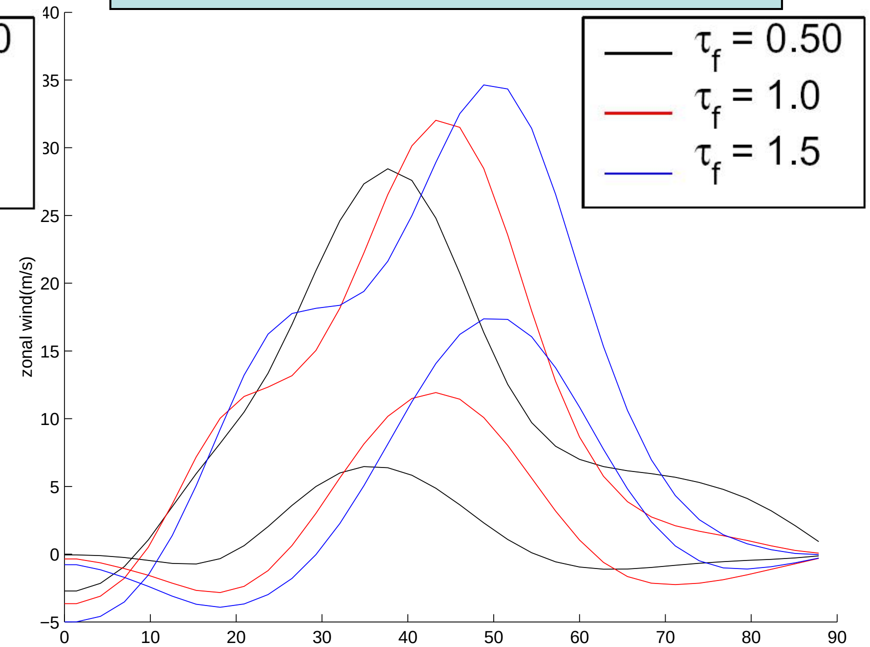
Zonal Wind @275mb and 825mb

$u_z(\tau_{fz},\tau_{f0})$ (Mean damping)



Latitude

$u(\tau_{fz},\tau_{fe})$ (Total damping)



Latitude

Extratropical zonal winds are primarily determined by the friction on the mean flow rather than the friction on the eddies.

Numerical Experiments

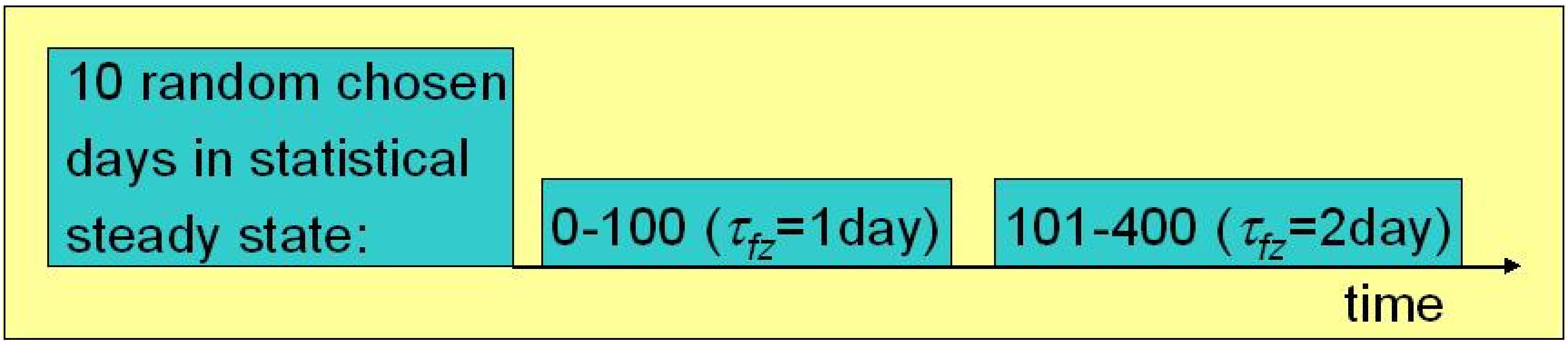
- 1. Model description and characteristics
- 2. Sensitivity to various values for surface friction
- 3. Sensitivity to various values for friction acting on eddy or mean flow

  $\Rightarrow$ drag on the mean flow is more important
- 4. Ensemble experiments

  $\Rightarrow$ the instantaneous response of the atmosphere to the friction change on the mean flow
- 5. Diagnostics in the PV perspective of view

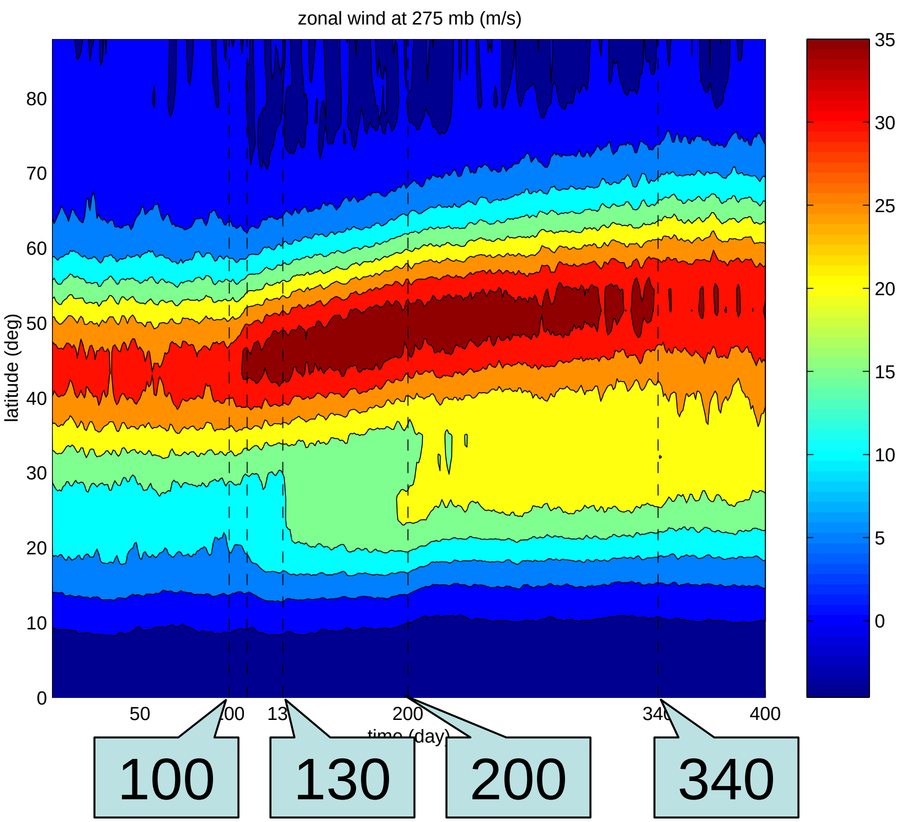
  $\Rightarrow$ two layer isentropic model

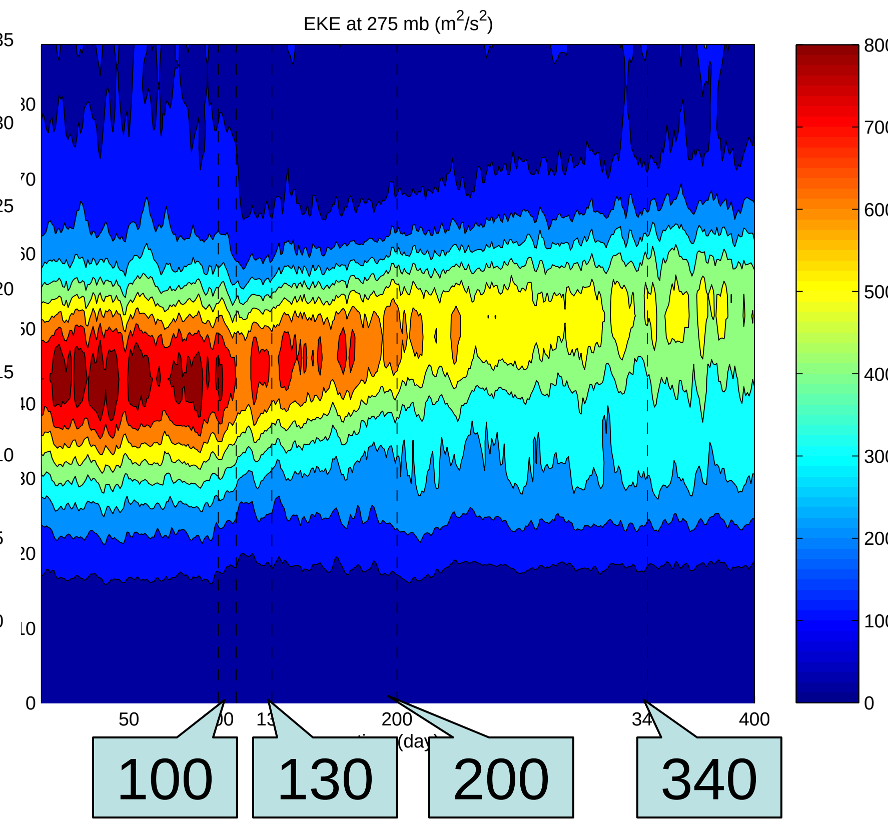
Ensemble Experiments



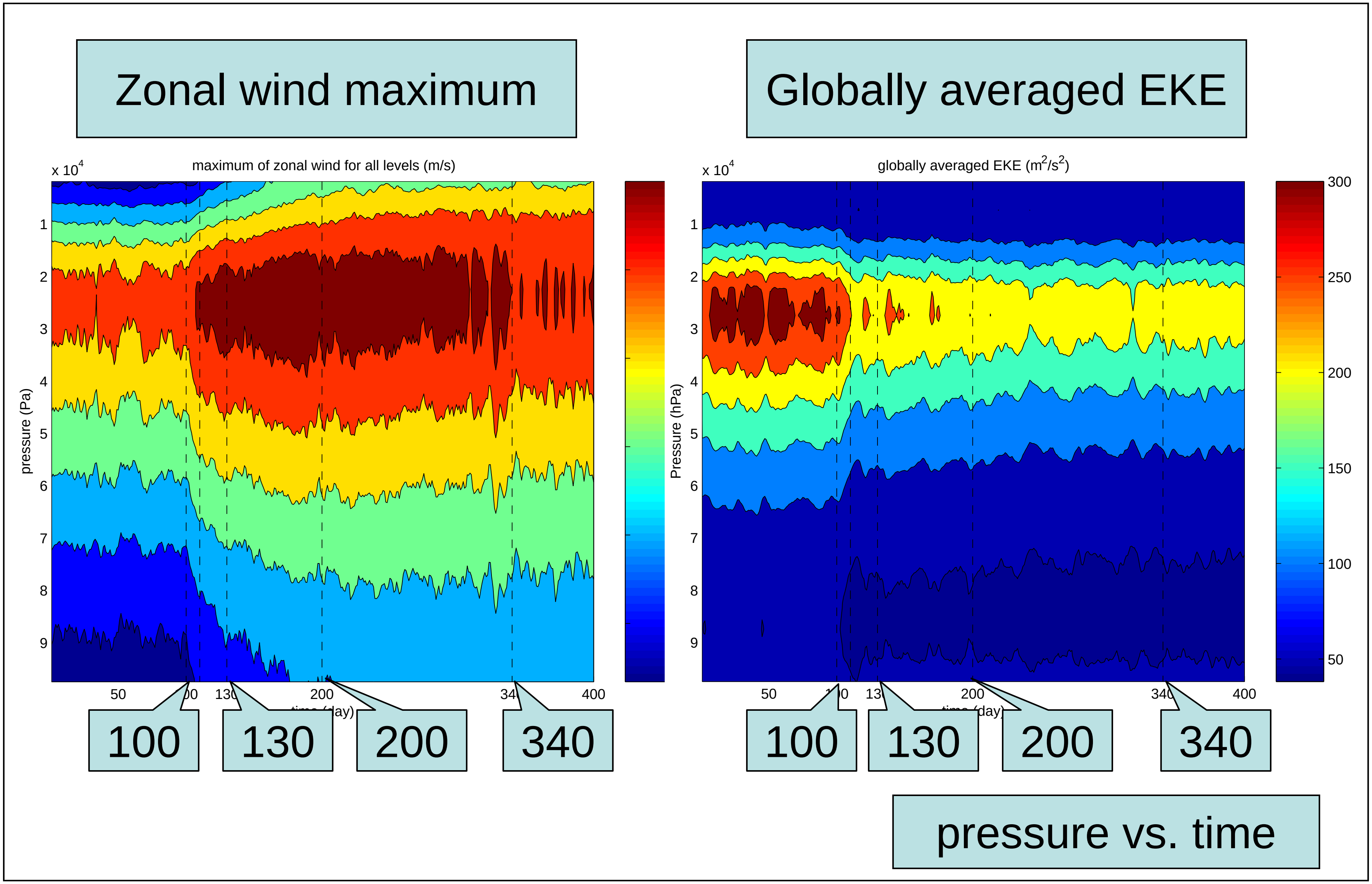
Zonal wind @275mb

EKE @275mb





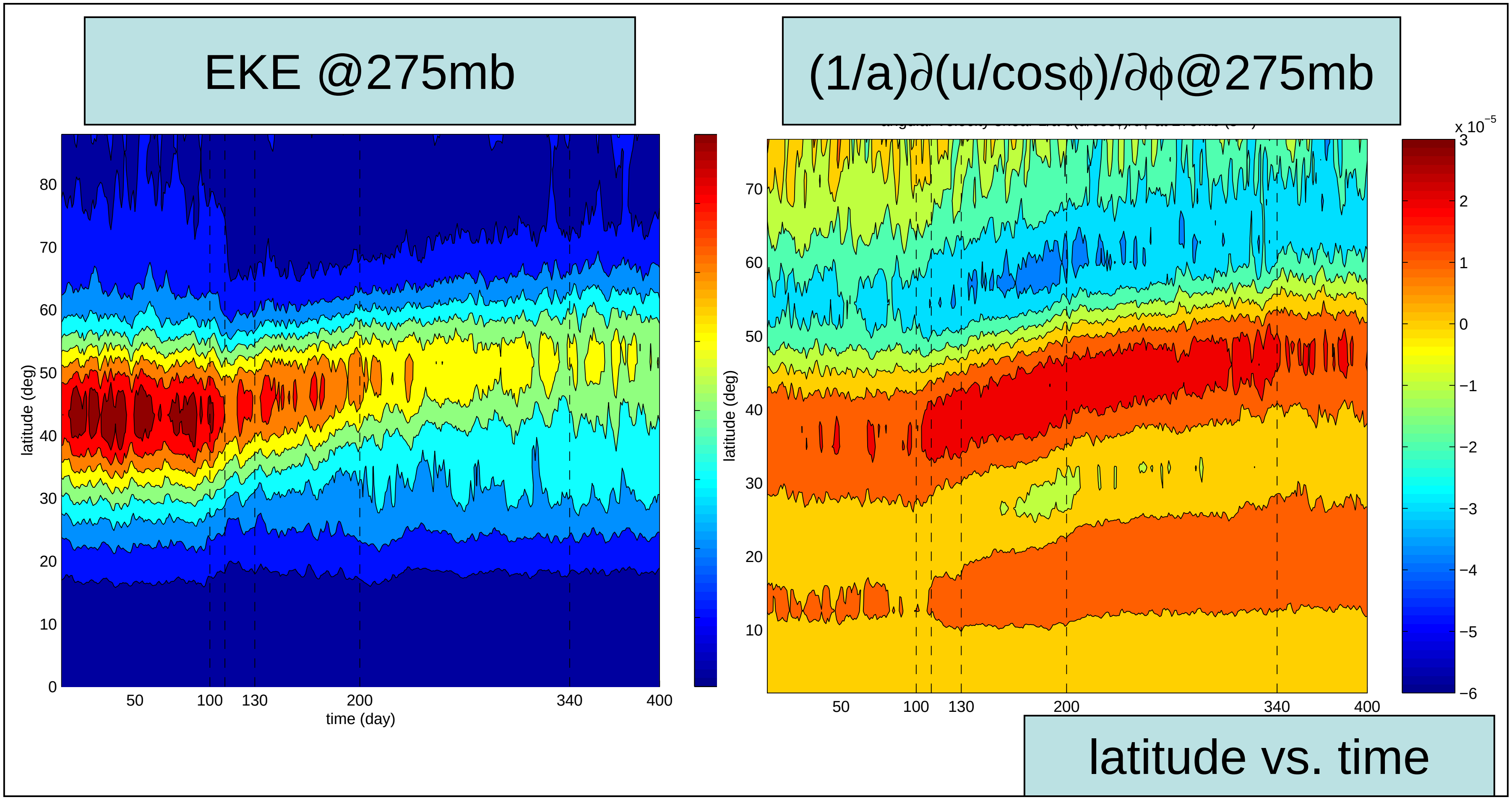
latitude vs. time



Zonal wind maximum
Globally averaged EKE
maximum of zonal wind for all levels (m/s)
x 10^4
pressure (Pa)
1
2
3
4
5
6
7
8
9
50
200
400
globally averaged EKE (m^2/s^2)
Pressure (hPa)
300
250
200
150
100
50
100
130
200
340
pressure vs. time

Barotropic governor

- Horizontal shear suppresses the growth rates of the most unstable modes. (James, 1987, 1986)



Numerical Experiments

- 1. Model description and characteristics
- 2. Sensitivity to various values for surface friction
- 3. Sensitivity to various values for friction acting on eddy or mean flow

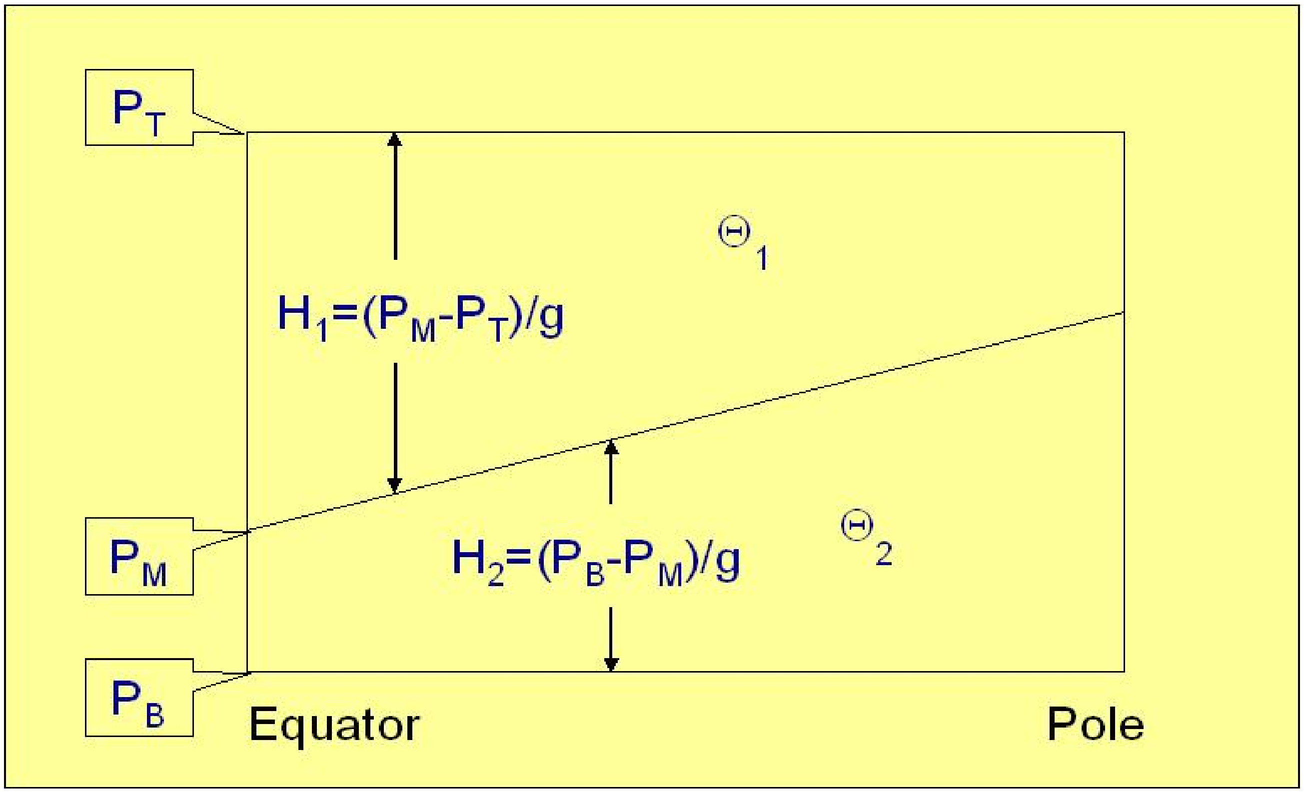
  $\Rightarrow$ drag on the mean flow is more important
- 4. Ensemble experiments

  $\Rightarrow$ the instantaneous response of the atmosphere to the friction change on the mean flow
- 5. Diagnostics in the PV perspective of view

  $\Rightarrow$ two layer isentropic model

Two layer isentropic model

- Two isentropic layers ($\Theta_1 > \Theta_2$)
- P_T is fixed, P_M, P_B are allowed to vary.



Meridional cross section

$$H_i(x,y) \;=\; H_{0,i}(y) + H_i'(x,y),\;\; i=1,2 \quad (1)$$

The quasi-geostrophic PV

$$q_i \;=\; \beta y + \zeta_i - \frac{f_0 H_i'}{H_{0,i}}, \qquad i=1,2 \qquad (2)$$

Define the residual circulation

$$v_i^* = \frac{\overline{v_i H_i}}{H_{0,i}} = \frac{\overline{v_i' H_i'}}{H_{0,i}}, \qquad i=1,2 \qquad (3)$$

The Transformed Eulerian Mean equation

$$\frac{\partial \bar{u}_1}{\partial t} \;=\; f v_1^* + \overline{v_1' q_1'} \qquad (4)$$

$$\frac{\partial \bar{u}_2}{\partial t} \;=\; f v_2^* + \overline{v_2' q_2'} - \frac{\bar{u}_2}{\tau_f} \qquad (5)$$

The thickness flux relationship

$$v_1^* H_{0,1} = -v_2^* H_{0,2} \qquad (6)$$

In the steady state

$$\boxed{\overline{v_1' q_1'} H_{0,1} + \overline{v_2' q_2'} H_{0,2} = \frac{\bar{u}_2}{\tau_f} H_{0,2}} \qquad (7)$$

PV flux and surface wind

$$\overline{v_1'q_1'}H_{0,1} + \overline{v_2'q_2'}H_{0,2} = \frac{\bar{u}_2}{\tau_f}H_{0,2}$$

$$\int \overline{v_1'q_1'}H_{0,1}dy + \int \overline{v_2'q_2'}H_{0,2}dy = 0$$

Held 2000

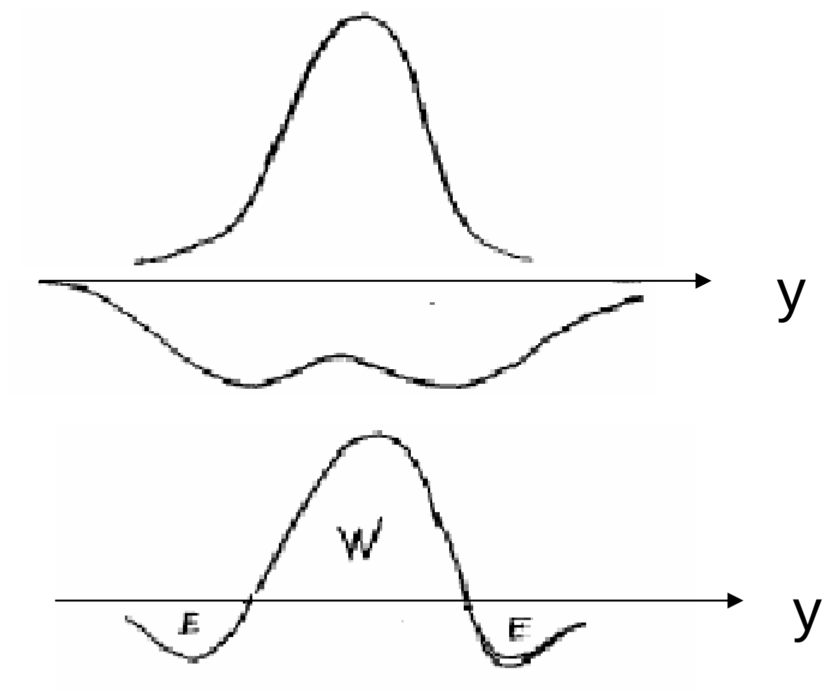
$\overline{v_2'q_2'}H_{0,2}$

+

$\overline{v_1'q_1'}H_{0,1}$

=

$\frac{\bar{u}_2}{\tau_f}H_{0,2}$



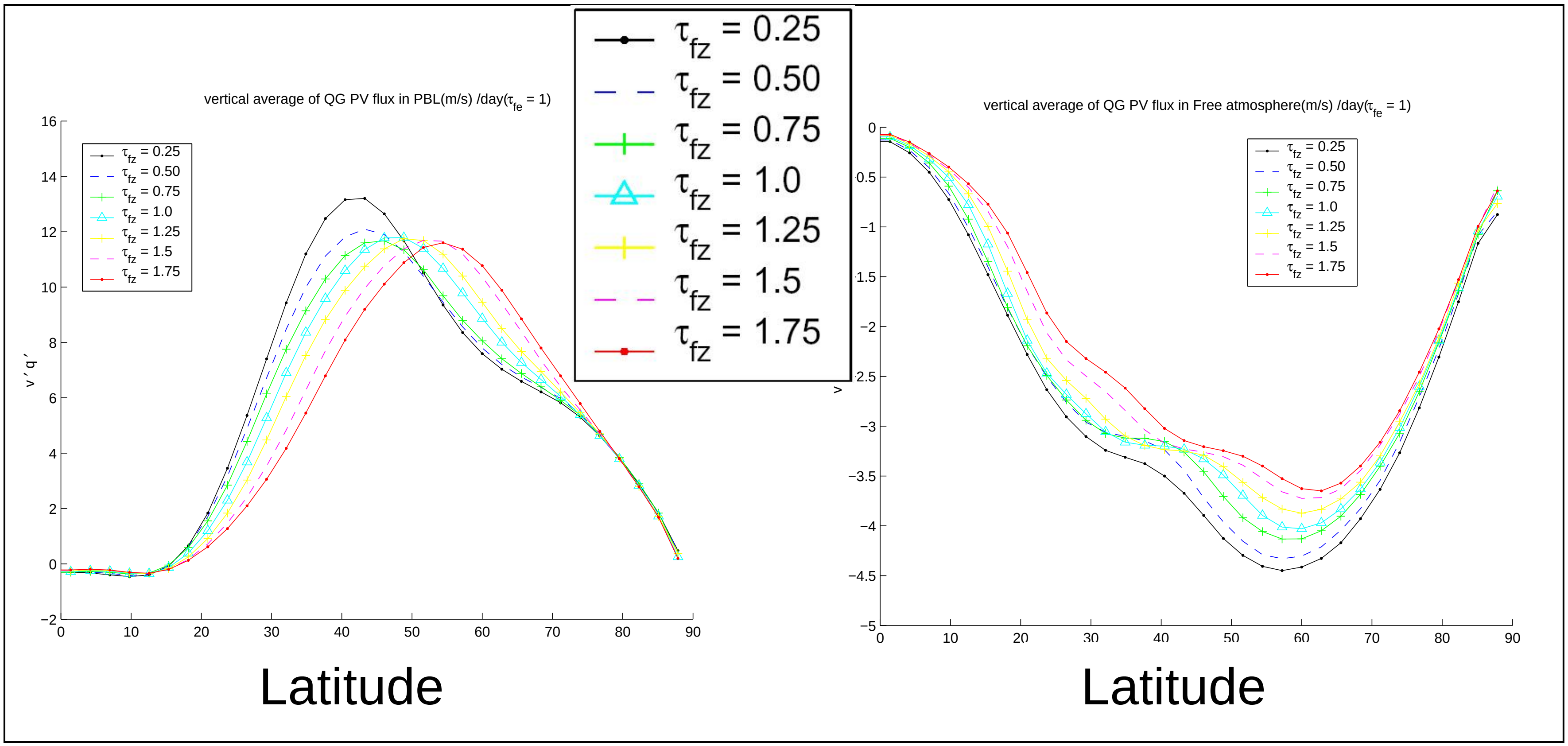
Lower PV flux

Upper PV flux

Surface wind

PV flux (700-1000mb avg)

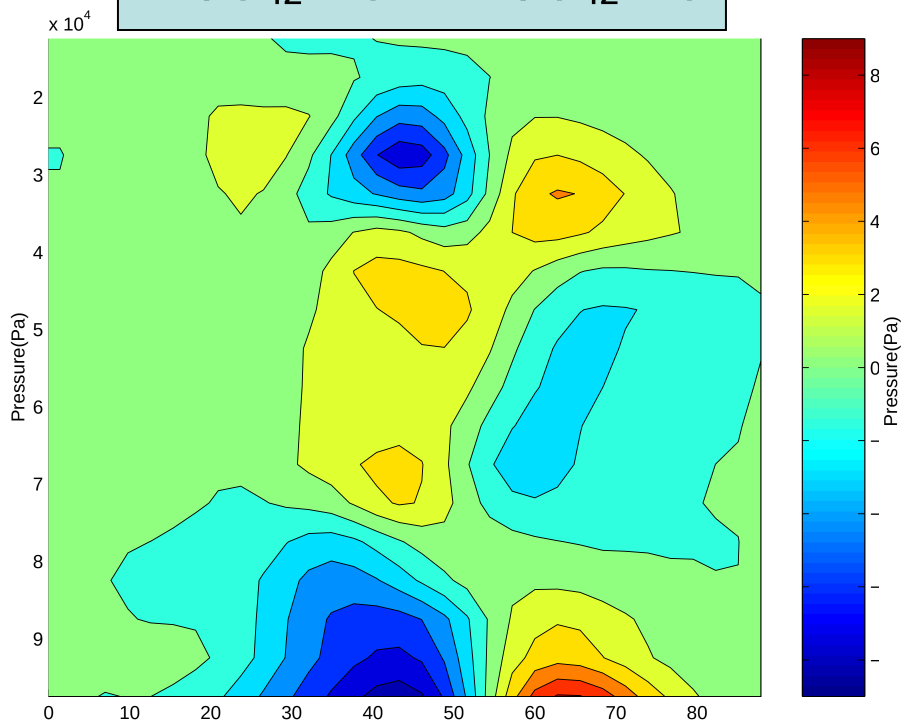
PV flux (0-700mb avg)



PV flux near the surface shifts further northward than PV flux in the free atmosphere if surface friction is reduced.

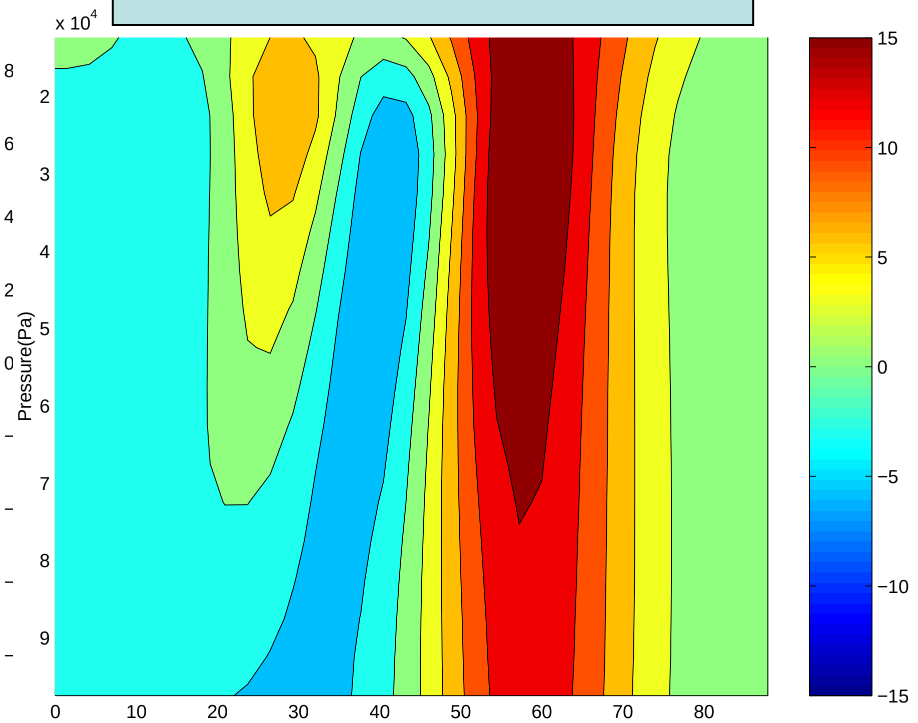
In the continuous atmosphere

$v'q'(\tau_{fz}=2) - v'q'(\tau_{fz}=1)$



Latitude

$u(\tau_{fz}=2) - u(\tau_{fz}=1)$



Latitude

The shift of PV flux near the surface induces the shift in the zonal wind.

Summary

- 1. The jet shifts poleward if the surface friction is reduced.
- 2. Extratropical zonal winds are primarily determined by the friction acting on the mean flow rather than the friction on the eddies.
- 3. If the surface friction on the mean flow is reduced, the zonal wind will increase barotropically. In the meanwhile, eddies become weaker due to barotropic governor mechanism.
- 4. If surface friction is reduced, PV flux near the surface shifts further northward than PV flux in the free atmosphere. The shift of PV flux near the surface induces the shift in the zonal wind.

Future work

- 1. Theory:

  Why would the PV flux near the surface shift poleward when surface friction is reduced?
- 2. Experiments:

  The jet latitude also varies with the radiative forcing.
- 3. Application of jet shift to a more realistic atmosphere.